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ANOPHELINE ECOLOGY AND MALARIA TRANSMISSION AT A NEW IRRIGATION PROJECT AREA (BARGI DAM) IN JABALPUR (CENTRAL INDIA)

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ABSTRACT. Anopheline ecology and malaria transmission were studied in a newly irrigated area of the Bargi Project, District Jabalpur, Madhya Pradesh, Central India. Observations were made for 2 years (1993–95) in 10 villages along the Bargi irrigation canal, which are situated between 44 km (head end of canal) and 78 km (tail end of canal) from the dam site. *Anopheles annularis* was the predominant species in the head-end villages and its abundance was directly related to the opening of the canal, whereas *Anopheles culicifacies* was the most abundant species in tail-end villages, where irrigation is limited. *Anopheles culicifacies* showed 2 typical peaks not related to canal irrigation. Site-related differences in species prevalence were significant in both immatures and adults. Malaria infection was due to *Plasmodium vivax* and *Plasmodium falciparum.* The annual parasite incidence in children and adults was significantly higher in head-end villages (>4-fold) as compared to that in tail-end villages. However, seasonal trends in the prevalence of *P. falciparum* and *P. vivax* were the same in each group, with some fluctuations. In this study, preliminary results of the investigation are presented, demonstrating the trends in anopheline ecology and parasite prevalence in relation to the dynamics of irrigation development.

KEY WORDS Malaria, irrigation, *Anopheles, Anopheles culicifacies, Plasmodium vivax, Plasmodium falciparum*

INTRODUCTION

Madhya Pradesh, Central India, the largest state in the country (442,841 km^2), lies in the geographical heart of India. It is a rural agricultural state marked by severe poverty and underdevelopment. The food grain production, infrastructure development, and irrigation expansion in the state are the lowest in the country (Tewari 1984). Construction of a series of multipurpose projects for the development of the state have been proposed. The Narmada Valley Development Project is the largest of the river valley projects so far proposed in India (Anonymous 1992). Bargi Dam, also known as Rani Avanti Bai Sagar Dam, a multipurpose irrigation and hydroelectric project (1974–88) is the 1st completed project in Jabalpur. Water has been stored to its full capacity (422.26 m full river level) since 1990. The main left bank canal is 137 km long and total length of the canal along with distributories is about 3,645 km (Anonymous 1984). The total area proposed to be irrigated by the left bank canal is 160,000 ha. Construction of a 194-km-long right bank canal to irrigate another 250,000 ha of land has been proposed. Traditionally, this study area was understood to be only mildly prone to malaria and hence no studies have been done on mosquitoes and malaria in the districts through which the left bank canal passes. However, these developments might have resulted in ecological changes that can have a major impact on the incidence of mosquito-borne diseases. Such an effect has been observed during the developmental projects of Sardar Sarovar, a downstream project of Narmada in Gujarat (Kalra 1992) and the Tava Project on a tributary of the Narmada in Hoshangabad, Madhya Pradesh (Chaudhary 1996).

This study was undertaken in villages along the Bargi Canal. A major aspect of the study focused on tracking the abundance and seasonality of anophelines and the incidence of malaria in a study area in the newly developed irrigation project. This paper presents evidence of the formation of new disease foci in the hitherto less malarious area, presumably under pressure of development. This case study may serve as a mode for rethinking malaria control programs under changing environmental and ecological conditions due to developmental projects.

MATERIALS AND METHODS

Study area: The study was carried out for 2 years (1993–95) in 10 villages (5 from Jabalpur and 5 from Narshinghpur) along the Bargi main left bank canal. Irrigation commenced in 1990 and the irrigation system became fully operational in 1991. The region falls within the lowland dry zone of the state (elevation 360–411 m) with a generally flat terrain interrupted by small foothills. Weather conditions recorded at the nearest Agricultural Engineering College (Jabalpur) for the 3 years from 1993 to 1995 were, respectively, total annual rainfall 1,486, 2,083, and 1,417 mm; mean maximum temperature 31.7, 30.90, and 31.60°C; mean minimum temperature 18.3, 18.2, and 18.8°C; and mean relative humidity 59.90, 60.70, and 63.40%.

Head-end villages: Five villages, Dabhola, Bichua, Nunpur, Chhapara, and Bijori, are referred to as head-end villages (total population, 2,302) because they are located between 44 and 50 km (Fig.

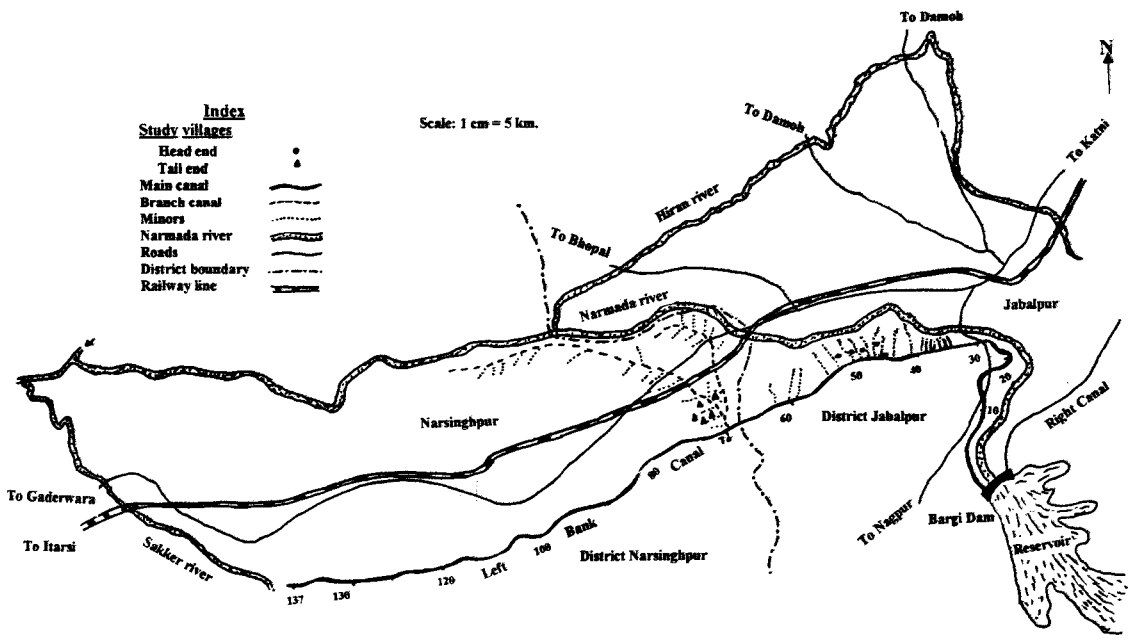

Fig. 1. Map showing Bargi left bank canal and location of study villages.

1) from the dam site (the 1st 39 km were not under irrigation). Out of the 5, 4 have direct water supply from the main canal through minor canals (minors). Only 1 village shares its water from Chhapra minor. Dabhola is the only village through which the main canal passes; the other villages are at about 0.5–1.0 km distant from the main canal. All the villages are sparsely populated (scheduled caste 45%, scheduled tribe 50%, and general 5%). The total proposed area under irrigation is 649 ha. A very good network of subminors and distributories exists, yet at the time of this study, they were not completely lined. Only 50% of the lining work was completed in patches. The water supply for irrigation is excellent from October to April during each year. The average discharge flow in the main canal is 10–15 m^3/sec and in minor canals it is 1–2 m^3/sec. The main crops are rice, maize, and wheat. These villages were under regular hexachlorohexane (HCH) spray (200 mg/m^2, 3 rounds each year) for malaria control in the months of May, July, and September. Use of HCH has been banned in India since 1997.

Tail-end villages: Ponia, Kukla, Manakwara, Piparia, and Dabkia were selected as tail-end villages (total population, 3,896) because they are located at a distance of 75–78 km (Fig. 1) from the dam site (of the 137-km-long main canal, only 80 km are constructed for irrigation). These villages are irrigated through 2 minors of the Hareri branch canal (water flow 5–10 m^3/sec). The total proposed area under irrigation is 868 ha, according to available records. Irrigation facilities and a network of irrigation canals exist, although water supply is not as good as in head-end villages. The main crop is soybeans followed by wheat. The villages are under routine dichlorodiphenyltrichloroethane (DDT) spray (1 g/m^2, 2 rounds each year) for malaria control in the months of May and August.

Mosquito sampling: Indoor resting mosquitoes (per man hour) were collected once a month from November 1993 to October 1995 from 2 villages, 1 from the head-end villages (24 collections) and 1 from the tail-end villages (24 collections) using standard entomological techniques (WHO 1975). *Anopheles* resting inside 4 selected sites located in different parts of each village (2 human dwellings and 2 cattle sheds) were sampled in the early morning (0600 hrs) for 15 min each by a team of 2 insect collectors with flashlights and mouth aspirators. All adult mosquitoes collected were identified morphologically in the laboratory using standard keys (Christophers 1933).

Bait collection: Anophelines attracted to human and animal baits were sampled from dusk to dawn at fixed stations once a month. Although we planned to station human baits both indoors and outdoors, only 1 human bait was seated on stool in the courtyard or verandah, where people sleep throughout the year, because of limited number of staff for this study and unavailability of volunteers. One additional collector caught anophelines attracted to buffalo baits (1 inside the house and 1 outside the house) for 15 min each hour.

Only indoor resting anophelines were dissected for presence of sporozoites in salivary glands. Parity determinations were done only in *Anopheles culicifacies* Giles, because of its availability throughout the year in both villages. Although

Anopheles fluviatilis James, *Anopheles annularis* Van der Wulp, *Anopheles subpictus* Grassi, and *An. culicifacies* have been identified as species complexes and the members of each complex can be distinguished by cytogenetic or DNA probe techniques, we did not attempt to identify the mosquitoes further under the primitive field conditions.

Larval sampling: Larval surveys were carried out once a month with standard dippers (250-ml capacity) from 1 village in each group. Larvae were collected from the main canal and associated minors and ditches and density per dip was recorded. One dip every 2 m was taken in the slow-running main canal and in the branch canal (15 dips in all). About 10–15 dips were taken from pools along the canal, ditches, and other breeding places depending on the area of the pools and pits. All these breeding sites were surveyed for 10 months in each year. In minors, seepages, and rice fields dips were taken at 1-m intervals (10–15 dips) from 4 to 8 months in a year depending on the availability of water. Only 3rd- and 4th-stage larvae and pupae were retained for adult emergence and identification.

Malaria surveillance: Blood smears were prepared twice a month from all current fever cases and people who reported fever during the preceding 14 days (active case detection) from all the 10 villages. All people with fever were given 600 mg chloroquine as presumptive treatment. Blood smears were stained with Giemsa and thick smears were examined under oil-immersion lens in the laboratory. Parasite-positive cases were given treatment as per the National Anti Malaria Programme (NAMP). Under this regimen, people with *Plasmodium vivax* malaria were administered 600 mg chloroquine as a single dose followed by 15 mg primaquine daily for 5 days and people with *Plasmodium falciparum* malaria were given 1,500 mg chloroquine on 3 days (600 mg on day 0, 600 mg on day 1, and 300 mg on day 2) and 45 mg primaquine as a single dose. Children were given proportionately lower doses according to age. Pregnant women and infants were not given primaquine.

Data analysis: The following definitions apply to this study. Per man-hour density: the number of mosquitoes collected by 1 insect collector in 1 h. Parity rate: the number of parous mosquitoes in the total number of mosquitoes dissected. Slide positivity rate: total number of blood smears found positive for malaria parasite in the total number of blood smears examined. Slide falciparum rate: total number of blood smears found positive for *P. falciparum* in the total number of blood smears examined. *Plasmodium falciparum* percentage (Pf%): total number of blood smears found positive for *P. falciparum* in the total number of blood smears positive for the malaria parasite. Annual blood examination rate (ABER): number of blood smears examined in a year in the total population under malaria surveillance. Annual parasite incidence (API): the proportion of the total number of blood smears found positive for malaria parasites in a year per 1,000 persons.

RESULTS

Larval ecology

In all, 3,929 larvae were collected in 1,530 dips in the head-end village and 3,451 larvae were collected in 1,526 dips in the tail-end village. Seven anopheline species were identified after adult emergence from larvae collected from irrigation canals and their various components. Percent emergence of the 5 most commonly collected species is shown in Table 1. In slow-flowing water of the main canal and minors, *An. culicifacies* predominated and accounted for more than 80% of the anophelines collected (range 70–94%) in both villages. Larvae of anopheline species breed extensively in ditches and pools along the canals in both villages, whereas rice fields support relatively less anopheline breeding and *An. culicifacies* was found breeding in freshly transplanted and fallow paddy fields. The other breeding places included slow-flowing water at the grassy edges of agricultural fields and borrow pits. *Anopheles subpictus* was found mainly in rice fields, ditches, and in pools along the canals in both villages, although some larvae of this species were found in the main canal and minors. *Anopheles annularis* was found primarily in seepage pools in the head-end village, whereas few were recorded from the main canal and rice fields from either of the villages. *Anopheles fluviatilis* and *Anopheles stephensi* Liston were recorded from the head-end village only in small numbers, and were not recorded from the tail-end village at all.

Indoor resting collections

In all, 8 anopheline species were collected in indoor resting collections from the head-end village and 9 were collected from the tail-end village. Data relating to the 3 most prevalent species collected are presented in Table 2. *Anopheles annularis* was the most dominant species (45.5%) collected at the head-end village followed by *An. culicifacies* (39.5%) and *An. subpictus* (12.5%). At the tail-end village, *An. culicifacies* was the most prevalent species (59.9%) followed by *An. subpictus* (31.1%) and *An. annularis* (5.7%). *Anopheles fluviatilis* was less than 1% in both the groups of villages. The percentage composition of these species differed significantly ($\chi^2 = 43.06$, df 2, $P < 0.0001$).

Seasonal abundance of *An. annularis* at the head-end village was directly related to the opening of the canals (October–April) during each year of the study. Abundance of *An. culicifacies* was high throughout the year with a main peak in July–September and a 2nd small peak in February–April in both the villages. *Anopheles subpictus* was most abundant during the rainy season, that is, July–Sep-

Table 1. Anopheline larval density (per dip) and emergence in villages along Bargi Canal.

Breeding sites surveyed	Larval density (mean)	Total larvae (%)	% emergence[1]				
			An. culicifacies	*An. subpictus*	*An. annularis*	*An. fluviatilis*	*An. stephensi*
Head end							
Main canal	2.8	764 (19.4)	84.3	2.2	12.0	0.0	0.0
Minors	1.0	180 (4.6)	94.2	3.8	1.9	0.0	0.0
Pools along canal	2.3	681 (17.3)	76.2	19.8	3.2	0.0	0.8
Ditches	4.2	1168 (29.7)	67.4	25.8	4.5	0.0	1.1
Pools due to seepage	2.3	151 (3.8)	54.0	0.0	46.0	0.0	0.0
Rice fields	3.0	360 (9.2)	44.2	43.5	10.2	2.0	0.0
Others	2.1	625 (15.9)	40.1	23.0	34.4	1.3	0.6
All	2.53	3929	65.8	16.9	16.03	0.5	0.36
Tail end							
Main canal (branch canal)	2.4	660 (19.1)	70.4	17.0	12.0	0.0	0.0
Minors	1.5	437 (12.6)	79.0	19.0	0.9	0.0	0.0
Pools along canal	2.3	679 (19.7)	73.8	21.5	4.6	0.0	0.0
Ditches	3.2	1306 (37.8)	52.6	44.3	1.5	0.0	0.0
Pools due to seepage	1.0	99 (2.8)	67.0	33.0	0.0	0.0	0.0
Rice fields	1.9	220 (6.4)	35.3	59.8	4.9	0.0	0.0
Others	0.8	50 (1.4)	61.5	38.5	0.0	0.0	0.0
All	1.87	3451	62.8	33.3	3.41	0.0	0.0

[1] *An., Anopheles.*

tember in 2 villages. Seasonal fluctuations were less predictable for *An. fluviatilis* because of their small numbers. Other species such as *Anopheles theobaldi* Giles, *Anopheles splendidus* Koidzumi, and *Anopheles vagus* Donitz were only rarely collected. Cattle bait collections showed the same trend of *Anopheles* prevalence in 2 villages (Table 3) as was found in the indoor resting collections.

Human bait collection

Only 19 and 11 females were collected during 12 human bait collections at head-end and tail-end villages, respectively. *Anopheles culicifacies* was most prevalent (1.1 per bait night) followed by *An. annularis* (0.33 per bait night) and *An. subpictus* (0.2 per bait night) at the head-end village. From the tail-end village, *An. culicifacies* was the most common (0.6 per bait night) followed by *An. subpictus* (0.3 per bait night) and *An. annularis* (0.1 per bait night).

Salivary gland dissection

Overall, 400 *An. culicifacies,* 13 *An. fluviatilis,* 50 *An. annularis,* and 50 *An. subpictus* were dis-

Table 2. Number of anopheline adults collected during indoor resting catches (man-hour density, 1993–95) in villages along Bargi Canal.[1]

Month	Head-end village				Tail-end village			
	An. culicifacies	*An. annularis*	*An. subpictus*	Total[2]	*An. culicifacies*	*An. annularis*	*An. subpictus*	Total[2]
Nov.	12 (10.1)	91 (76.5)	3 (2.5)	119	19 (67.9)	0 (0.0)	6 (21.4)	28
Dec.	17 (17.3)	65 (66.3)	3 (3.1)	98	17 (43.6)	4 (10.3)	15 (38.5)	39
Jan.	22 (23.9)	59 (64.1)	8 (8.7)	92	25 (10.2)	3 (6.1)	21 (42.9)	49
Feb.	47 (27.6)	120 (70.6)	2 (1.2)	170	37 (59.7)	4 (6.5)	20 (32.3)	62
March	73 (52.1)	64 (45.7)	2 (1.4)	140	49 (61.3)	12 (15.0)	19 (23.8)	80
April	30 (32.6)	60 (65.2)	2 (2.2)	92	50 (79.4)	0 (0.0)	13 (20.6)	63
May	20 (37.0)	29 (53.7)	5 (9.3)	54	12 (54.5)	0 (0.0)	10 (45.5)	38
June	35 (52.2)	22 (32.8)	10 (14.9)	67	8 (57.1)	1 (7.1)	5 (35.7)	14
July	66 (61.7)	17 (15.9)	22 (20.6)	107	25 (59.5)	1 (2.4)	16 (38.1)	42
Aug.	143 (75.3)	6 (3.2)	39 (20.5)	190	72 (63.2)	0 (0.0)	40 (35.1)	114
Sept.	75 (37.7)	51 (25.6)	73 (36.7)	199	99 (55.6)	10 (5.6)	69 (38.8)	178
Oct.	40 (28.8)	84 (60.4)	15 (10.8)	139	67 (71.3)	11 (11.7)	15 (16.0)	94
Total	580 (39.5)	668 (45.5)	184 (12.5)	1467	480 (59.9)	46 (5.7)	249 (31.1)	801

[1] *An., Anopheles.* Numbers in parentheses indicate percentage of total collected during month for each village.

[2] *Anopheles fluviatilis, An. theobaldi, An. splendidus, An. stephensi,* and *An. vagus* are included in the head-end village and these species along with *An. nigerrimus* are included in tail-end village.

Table 3. Number of anophelines collected on animal baits in Bargi Canal villages (1993–94).[1]

Month	Head-end village				Tail-end village			
	An. culicifacies	*An. annularis*	*An. subpictus*	Total	*An. culicifacies*	*An. annularis*	*An. subpictus*	Total
Nov.	2	68	3	74	—	—	—	—
Dec.	5	97	3	105	7	1	12	21
Jan.	8	80	2	92	2	0	23	25
Feb.	43	52	1	104	17	0	14	32
March	35	48	2	86	38	1	6	45
April	8	23	7	38	7	2	15	24
May	6	16	11	33	9	0	12	21
June	1	8	5	14	2	0	5	7
July	13	2	6	21	5	1	27	33
Aug.	180	13	30	224	153	1	13	172
Sept.	53	0	21	75	41	0	22	64
Oct.	7	44	2	53	73	3	5	80
Total	308 (12.8)	451 (18.8)	72 (3.0)	844 (35.3)	366 (16.6)	12 (0.5)	153 (6.9)	536 (24.3)

[1] *An., Anopheles.* Figures in parentheses indicate per bait per night.

sected from head-end villages to determine sporozoite infection. Only 1 *An. culicifacies* was positive for sporozoites in the month of August 1995. None of the remaining species dissected was sporozoite positive. From the tail-end village, the salivary glands from 136 *An. culicifacies,* 25 *An. annularis,* and 25 *An. subpictus* were examined for sporozoites. None was positive for sporozoites.

Parity status

Parity rates of *An. culicifacies* varied from 56 to 69% (95%, CI 4.3–30.3%) at the head-end village and 41–75% (95%, CI 11–57%) at the tail-end village (Table 4). The difference between the head-end village and the tail-end village is significant statistically ($\chi^2 = 20.06$, df 9, $P \leq 0.01$).

Pattern of malaria prevalence in active surveillance

Data were combined per month over villages (Tables 5 and 6) to examine seasonal changes in malaria prevalence between children (<14 years old) and adults (>14 years old). A similar seasonal pattern of *P. vivax* and *P. falciparum* infections was found in both children and adults in each year of the study with some fluctuations. *Plasmodium vivax* cases began to appear from April to May and continued until September to October. *Plasmodium falciparum* cases were found mainly from July to December and very few *P. falciparum* cases were recorded during March to June. Overall, Pf% was higher in adults (69%) as compared to children (39%) at head-end villages (Table 5), which is highly significant statistically ($P < 0.0001$), whereas at tail-end villages (Table 6) the difference in Pf% between adults (66.5%) and children (53.4%) was significant at a low level ($P < 0.05$). In contrast, *P. falciparum* gametocyte carriers were significantly higher ($P < 0.001$) in children (16.5%) as compared to adults (6.7%) at head-end villages, whereas at tail-end villages the difference in *P. falciparum* gametocytes carriers was not significant between children (16%) and adults (10%).

When the data were pooled over villages and years and the ABER and API were compared between children and adults, both ABER and API were significantly higher in children (ABER, 76.7; API, 216) and adults (ABER, 73; API, 140) at head-end villages ($P < 0.00001$) as compared to children (ABER, 27; API, 57) and adults (ABER, 26; API, 33) at tail-end villages ($P < 0.00001$). Overall, 2.4 times more malaria cases and 2.2 times more *P. falciparum* cases were recorded from head-end villages than from tail-end villages. Further,

Table 4. Parity status of indoor-resting *Anopheles culicifacies* caught in villages along the Bargi Canal (Nov. 1993–Oct. 1995).

Month	Head-end village				Tail-end village			
	Total dissected	Parous	Nulli-parous	Parity (%)	Total dissected	Parous	Nulli-parous	Parity (%)
Nov.–Jan.	24	14	10	58.3	20	12	8	60.0
Feb.–April	55	31	24	56.4	37	19	18	51.3
May–July	44	28	16	63.6	22	9	13	40.9
Aug.–Oct.	64	44	20	68.8	71	53	18	74.6
Total	187	117	70	62.6	150	93	57	62.0

Table 5. Malaria prevalence in children (<14 years old) and adults (>14 years old) at head-end villages along Bargi Canal (1993–95).[1]

	Children					Adults				
Month/year	BSE	Pv	Pf	SPR	Pf%	BSE	Pv	Pf	SPR	Pf%
Nov.										
1993	119	17	30	39.5	63.8	455	0	67	14.7	100.0
1994	34	1	6	20.6	85.7	80	0	15	18.8	100.0
Dec.										
1993	43	2	12	32.6	85.7	157	0	22	14.0	100.0
1994	27	5	5	37.0	50.0	83	0	12	14.5	100.0
Jan.										
1994	41	1	5	14.6	83.3	94	2	13	16.0	86.7
1995	31	2	3	16.1	60.0	44	2	1	6.8	33.3
Feb.										
1994	27	1	3	14.8	75.0	51	0	4	7.8	100.0
1995	10	1	1	20.0	50.0	17	2	0	11.8	0.0
March										
1994	34	2	0	5.9	0.0	80	1	3	5.0	75.0
1995	4	2	0	50.0	0.0	8	1	0	12.5	0.0
April										
1994	50	9	2	22.0	18.2	89	6	10	18.0	62.5
1995	56	7	0	12.5	0.0	55	11	0	20.0	0.0
May										
1994	32	9	1	31.3	10.0	69	6	9	21.7	60.0
1995	41	8	0	19.5	0.0	69	19	1	29.0	5.0
June										
1994	43	7	1	18.6	12.5	107	5	3	7.5	37.5
1995	39	5	0	12.8	0.0	44	8	0	18.2	0.0
July										
1994	89	14	7	23.6	33.3	213	4	8	5.6	66.7
1995	62	11	0	17.7	0.0	64	9	11	31.3	55.0
August										
1994	80	23	16	48.8	41.0	126	8	24	25.4	75.0
1995	67	7	8	22.4	53.3	76	8	6	18.4	42.9
Sept.										
1994	117	31	13	37.6	29.5	211	4	57	28.9	93.4
1995	55	6	5	20.0	45.5	84	3	14	20.2	82.4
Oct.										
1994	87	22	15	42.5	40.5	158	0	37	23.4	100.0
1995	33	1	1	6.1	50.0	63	3	10	20.6	76.9

[1] BSE, blood slide examined; Pv, *Plasmodium vivax*; Pf, *P. falciparum*; SPR, slide positivity rate; Pf%, *P. falciparum* percentage.

API among infants at head-end villages was 161 and 22, respectively, during the 1st and 2nd years, whereas at tail-end villages the API among infants was 0 during both years (data not shown).

DISCUSSION

Large-scale irrigation developments often have resulted in increased human malaria incidence (Amerasinghe and Indrajith 1994, Tyagi and Chaudhary 1997). The effect of irrigation projects on the incidence of malaria varies with the type of irrigation employed, with the physiographic and climatic features of the area irrigated, and with the methods of cultivation practiced therein (Singh and Puri 1951). Mandla, Jabalpur, and Seoni districts are affected by the Bargi irrigation project. A major epidemic occurred in many villages near the Bargi Dam reservoir (Singh et al. 1997) and a steady increase in malaria incidence has been recorded in the Mandla District since 1991 (Singh et al. 1999a). This malaria is not responsive to control measures. Thus, malaria control requires specific approaches and control strategies for irrigation projects, which emphasizes the need for better understanding of the epidemiologic features and transmission dynamics of malaria. The Bargi irrigation project presented an oportunity for a case study on mosquito ecology and malaria in relation to irrigation development. Unfortunately, no figures are available to show how many anopheline species or how much malaria existed in the study area before the development of the irrigation canal.

Analysis of the results of the salivary gland dissections suggested that the only malaria vector is *An. culicifacies,* as recorded earlier (Singh et al. 1996, 1999b). However, too few mosquitoes were dissected to establish this definitively. A larger number of salivary glands could not be dissected because of the long distance between field sites and

Table 6. Malaria prevalence in children (<14 years old) and adults (>14 years old) at tail-end villages along Bargi Canal (1993–95).[1]

	Children					Adults				
Month/year	BSE	Pv	Pf	SPR	Pf%	BSE	Pv	Pf	SPR	Pf%
Nov.										
1993	63	5	22	42.9	81.5	179	4	23	15.1	85.2
1994	15	0	4	26.7	100.0	31	0	5	16.1	100.0
Dec.										
1993	31	1	8	29.0	88.9	72	0	11	15.3	100.0
1994	18	1	1	11.1	50.0	42	0	2	4.8	100.0
Jan.										
1994	20	2	4	30.0	66.7	62	0	0	0.0	0.0
1995	16	1	2	18.8	66.7	36	1	2	8.3	66.7
Feb.										
1994	19	0	4	21.1	100.0	52	0	2	3.8	100.0
1995	32	3	2	15.6	40.0	45	0	0	0.0	0.0
March										
1994	22	2	1	13.6	33.3	34	0	4	11.8	100.0
1995	21	0	0	0.0	0.0	50	2	1	6.0	33.3
April										
1994	16	1	0	6.3	0.0	25	0	2	8.0	100.0
1995	22	0	0	0.0	0.0	40	1	0	2.5	0.0
May										
1994	26	4	0	15.4	0.0	23	2	0	8.7	0.0
1995	29	3	2	17.2	40.0	61	5	1	9.8	16.7
June										
1994	29	3	1	13.8	25.0	21	4	0	19.0	0.0
1995	31	7	0	22.6	0.0	23	4	0	17.4	0.0
July										
1994	16	1	1	12.5	50.0	48	0	3	6.3	100.0
1995	47	3	0	6.4	0.0	72	8	0	11.1	0.0
Aug.										
1994	28	5	3	28.6	37.5	55	2	6	14.5	75.0
1995	36	2	1	8.3	33.3	67	0	3	4.5	100.0
Sept.										
1994	44	7	7	31.8	50.0	101	10	20	29.7	66.7
1995	44	5	3	18.2	37.5	85	2	8	11.8	80.0
Oct.										
1994	47	2	14	34.0	87.5	82	6	22	34.1	78.6
1995	18	0	2	11.1	100.0	43	2	10	27.9	83.3

[1] BSE, blood slide examined; Pv, *Plasmodium vivax*; Pf, *P. falciparum*; SPR, slide positivity rate; Pf%, *P. falciparum* percentage.

the laboratory (25 km from the head-end village and 50 km from the tail-end village). As a result, many mosquitoes died in transit (a constraint imposed by the nonavailability of enzyme-linked immunosorbent assay technology). Other known vectors, *An. fluviatilis* (Kulkarni 1987, Subbarao et al. 1992) and *An. stephensi* (Sharma, 1996), are present in the study area in small numbers from head-end villages. These 2 species may play a major role in malaria transmission if environmental changes favor increased breeding under conditions of canal irrigation.

In Sri Lanka, in the Mahaveli Project after irrigation development, an increase in abundance of *An. annularis* and *An. subpictus* was reported (Amerasinghe and Ariyasena 1990, Amerasinghe et al. 1991). Their data are consistent with high *An. annularis* and *An. subpictus* catches recorded from head-end and tail-end villages, respectively in this study. The 2 species were found in insignificant numbers during a limited period of the year in longitudinal studies carried out simultaneously in connection with another research project in nonirrigated villages about 20 km from the study area (Singh, unpublished data) or in other nonirrigated areas of Jabalpur (Singh and Sharma 1989, Singh and Mishra 1997) and in Mandla (Singh et al. 1996). The larval abundance pattern generally agreed with the adult pattern, but this was difficult to quantify because of differences in habitat size and the clumped distribution of larvae within habitats. Interestingly, all these species were highly zoophagic, as indicated by comparative human versus animal bait biting collections in the study area. However, *An. subpictus* was incriminated as the vector in Baster, Madhya Pradesh (Kulkarni 1983) and *An. annularis* was incriminated in Koraput, Orissa (Gunasekaran et al. 1989). Subsequent stabilization of the irrigation canals and an increase in natural and planted vegetation is likely to encourage the establishment of

some of these anopheline species as significant vectors of malaria, as recorded elsewhere (Tyagi and Chaudhary 1997).

Perennial irrigation systems tend toward overirrigation. The problem is worsened by the fact that canals are not lined and no drainage system is available. Narmada River is the largest monsoon river of Madhya Pradesh, hence the bulk of the runoff water is generated during monsoon months that are marked by spells of intense and heavy rainfall. Flooding of tracts by the overflow of silt-laden water from the Narmada River during the monsoon season creates scours in the bed. The original gradient was altered because of silt deposits, resulting in the obstruction of the free flow of water.

At head-end villages, temporary obstructions are commonly created by villagers during slow release to maximize the amount of water for their crops. During peak release, water escapes its banks and spreads to low-lying areas. In tail-end villages, nonavailability of sufficient water for the crop is a common phenomenon. Here, the illicit removal of water is a problem. Needless to say, the irrigation canal has provided additional breeding sites for anophelines by slowing the current in many places in which pools form. Intense breeding was recorded in temporary pools in the irrigation canals immediately after the water was shut off, as frequently occurs when repairs of the canal bank are necessary. Moreover, during the nonirrigation season, rainwater pools that support heavy breeding of anophelines are formed in the canals.

The incidence of malaria was very high in the study villages, particularly in the head-end villages in spite of the low human biting and sporozoite rate in *An. culicifacies*. Despite being a zoophilic species, *An. culicifacies* is known to be capable of transmitting malaria because of its dispersive behavior and longevity (Curtis and Rawlings 1980, Rawlings et al. 1981). Thus, the incidence of malaria in the villages studied here apparently is directly related to irrigation. In tail-end villages, where less irrigation is present, villages are less malarious. The decline in ABER and API during 2nd year of the study may be related to surveillance and drug distribution by project staff.

Of concern is that irrigation-related malaria is probably more prevalent in Madhya Pradesh now than ever before because of the construction of various major and minor developmental projects. Health issues seem to have been neglected in many development projects (Birley 1991). Several guidelines have been published to facilitate the assessment of health impacts for water resource projects and other types of development (Birley 1989). However, little has been done in practice. Poor engineering design is difficult to correct after construction, and hence early planning is critical. It is already too late for Bargi to prevent some of these consequences. Construction is progressing and action is required now to develop an effective health care program based on local transmission involving multisectoral action and community participation to prevent the spread of disease in the whole region.

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